

I CLAIM:

1. A method of forming a hardened surface on a substrate, comprising:
providing a substrate; and
forming a metallic glass coating on the substrate and having a first hardness of at least about 9.2 GPa, wherein the metallic glass comprises fewer than 11 elements.

2. The method of claim 1 further comprising converting at least a portion of the metallic glass coating to a crystalline material having a nanocrystalline grain size and a second hardness of at least about 9.2 GPa

3. The method of claim 2 wherein the substrate is a metallic material.

4. The method of claim 2 wherein the substrate is a ceramic material.

5. The method of claim 2 wherein the first hardness is at least about 10.0 GPa.

6. The method of claim 2 wherein the metallic glass comprises fewer than 7 elements.

7. The method of claim 2 wherein the metallic glass coating is applied to the substrate as a plasma spray.

1 8. The method of claim 2 wherein the forming the metallic glass coating
2 comprises an application of an atomized powder of a metallic glass material over the
3 substrate.

1 9. The method of claim 2 wherein the forming a metallic glass coating
2 comprises forming a successive buildup of continuous layers.

1 10. The method of claim 2 wherein the converting comprises heating the
2 metallic glass to above a crystallization temperature of the metallic glass.

1 11. The method of claim 10 wherein the heating comprises heating to a
2 temperature of at least about 600°C and below a melting temperature of the metallic
3 glass.

1 12. The method of claim 2 wherein the second hardness is at least about 10.0
2 GPa.

1 13. A method of forming a hardened surface on a substrate, comprising:
2 providing a substrate;
3 forming a metallic glass coating on the substrate; the metallic glass comprising
4 one or more materials selected from the group consisting of $(\text{Fe}_{0.85}\text{Cr}_{0.15})_{83}\text{B}_{17}$,

5 (Fe_{0.8}Cr_{0.2})₈₃B₁₇, (Fe_{0.75}Cr_{0.25})₈₃B₁₇, (Fe_{0.6}Co_{0.2}Cr_{0.2})₈₃B₁₇, (Fe_{0.8}Cr_{0.15}Mo_{0.05})₈₃B₁₇,
6 (Fe_{0.8}Cr_{0.2})₇₉B₁₇C₄, (Fe_{0.8}Cr_{0.2})₇₉B₁₇Si₄, (Fe_{0.8}Cr_{0.2})₇₉B₁₇Al₄, (Fe_{0.8}Cr_{0.2})₇₅B₁₇Al₄C₄,
7 (Fe_{0.8}Cr_{0.2})₇₅B₁₇Si₄C₄, (Fe_{0.8}Cr_{0.2})₇₅B₁₇Si₄Al₄, (Fe_{0.8}Cr_{0.2})₇₁B₁₇Si₄C₄Al₄, (Fe_{0.7}Co_{0.1}Cr_{0.2})₈₃B₁₇,
8 (Fe_{0.8}Cr_{0.2})₈₀B₂₀, (Fe_{0.8}Cr_{0.2})₇₆B₁₇Al₇, (Fe_{0.8}Cr_{0.2})₇₉B₁₇W₂C₂, (Fe_{0.8}Cr_{0.2})₈₁B₁₇W₂, and
9 Fe₆₄Ti₃Cr₅Mo₂B₁₆C₅Si₁Al₂La₂; and

10 converting at least a portion of the metallic glass coating to a crystalline material
11 having a nanocrystalline grain size.

1 14. The method of claim 13 wherein the metallic glass coating is applied to
2 the substrate by a plasma spray system.

1 15. The method of claim 13 wherein the forming the metallic glass coating
2 comprises an application of an atomized powder of a metallic glass material over the
3 substrate.

1 16. The method of claim 13 wherein the forming a metallic glass coating
2 comprises forming a successive buildup of continuous layers.

1 17. The method of claim 13 wherein the metallic glass coating comprises
2 (Fe_{0.85}Cr_{0.15})₈₃B₁₇.

1 18. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.85}\text{Cr}_{0.15})_{83}\text{B}_{17}$.

1 19. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.85}\text{Cr}_{0.15})_{83}\text{B}_{17}$.

1 20. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 21. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 22. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 23. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.75}\text{Cr}_{0.25})_{83}\text{B}_{17}$.

1 24. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.75}\text{Cr}_{0.25})_{83}\text{B}_{17}$.

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1 25. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.75}\text{Cr}_{0.25})_{83}\text{B}_{17}$.

1 26. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.6}\text{Co}_{0.2}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 27. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.6}\text{Co}_{0.2}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 28. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.6}\text{Co}_{0.2}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 29. The method of claim 13 wherein the metallic glass coating of comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.15}\text{Mo}_{0.05})_{83}\text{B}_{17}$.

1 30. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.15}\text{Mo}_{0.05})_{83}\text{B}_{17}$.

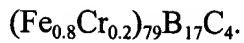
1 31. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.15}\text{Mo}_{0.05})_{83}\text{B}_{17}$.

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32. The method of claim 13 wherein the metallic glass coating comprises

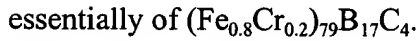
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33. The method of claim 13 wherein the metallic glass coating consists

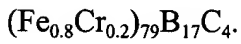
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34. The method of claim 13 wherein the metallic glass coating consists of

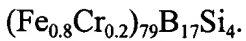
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35. The method of claim 13 wherein the metallic glass coating comprises

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36. The method of claim 13 wherein the metallic glass coating consists

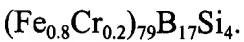
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37. The method of claim 13 wherein the metallic glass coating consists of

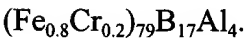
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38. The method of claim 13 wherein the metallic glass coating comprises

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1 39. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{79}\text{B}_{17}\text{Al}_4$.

1 40. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{79}\text{B}_{17}\text{Al}_4$.

1 41. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Al}_4\text{C}_4$.

1 42. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Al}_4\text{C}_4$.

1 43. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Al}_4\text{C}_4$.

1 44. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{C}_4$.

1 45. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{C}_4$.

1 46. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{C}_4$.

1 47. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{Al}_4$.

1 48. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{Al}_4$.

1 49. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{75}\text{B}_{17}\text{Si}_4\text{Al}_4$.

1 50. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{71}\text{B}_{17}\text{Si}_4\text{C}_4\text{Al}_4$.

1 51. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{71}\text{B}_{17}\text{Si}_4\text{C}_4\text{Al}_4$.

1 52. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{71}\text{B}_{17}\text{Si}_4\text{C}_4\text{Al}_4$.

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1 53. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.7}\text{Co}_{0.1}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 54. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.7}\text{Co}_{0.1}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 55. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.7}\text{Co}_{0.1}\text{Cr}_{0.2})_{83}\text{B}_{17}$.

1 56. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{80}\text{B}_{20}$.

1 57. The method of claim 13 wherein the metallic glass coating consists
2 essentially of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{80}\text{B}_{20}$.

1 58. The method of claim 13 wherein the metallic glass coating consists of
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{80}\text{B}_{20}$.

1 59. The method of claim 13 wherein the metallic glass coating comprises
2 $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{76}\text{B}_{17}\text{Al}_7$.

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67. The method of claim 13 wherein the metallic glass coating of claim 13 consists of $(\text{Fe}_{0.8}\text{Cr}_{0.2})_{81}\text{B}_{17}\text{W}_2$.

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68. The method of claim 13 wherein the metallic glass coating of claim 13 comprises $\text{Fe}_{64}\text{Ti}_3\text{Cr}_5\text{Mo}_2\text{B}_{16}\text{C}_5\text{Si}_1\text{Al}_2\text{La}_2$.

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69. The method of claim 13 wherein the metallic glass coating consists essentially of $\text{Fe}_{64}\text{Ti}_3\text{Cr}_5\text{Mo}_2\text{B}_{16}\text{C}_5\text{Si}_1\text{Al}_2\text{La}_2$.

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70. The method of claim 13 wherein the metallic glass coating of claim 13 consists of $\text{Fe}_{64}\text{Ti}_3\text{Cr}_5\text{Mo}_2\text{B}_{16}\text{C}_5\text{Si}_1\text{Al}_2\text{La}_2$.